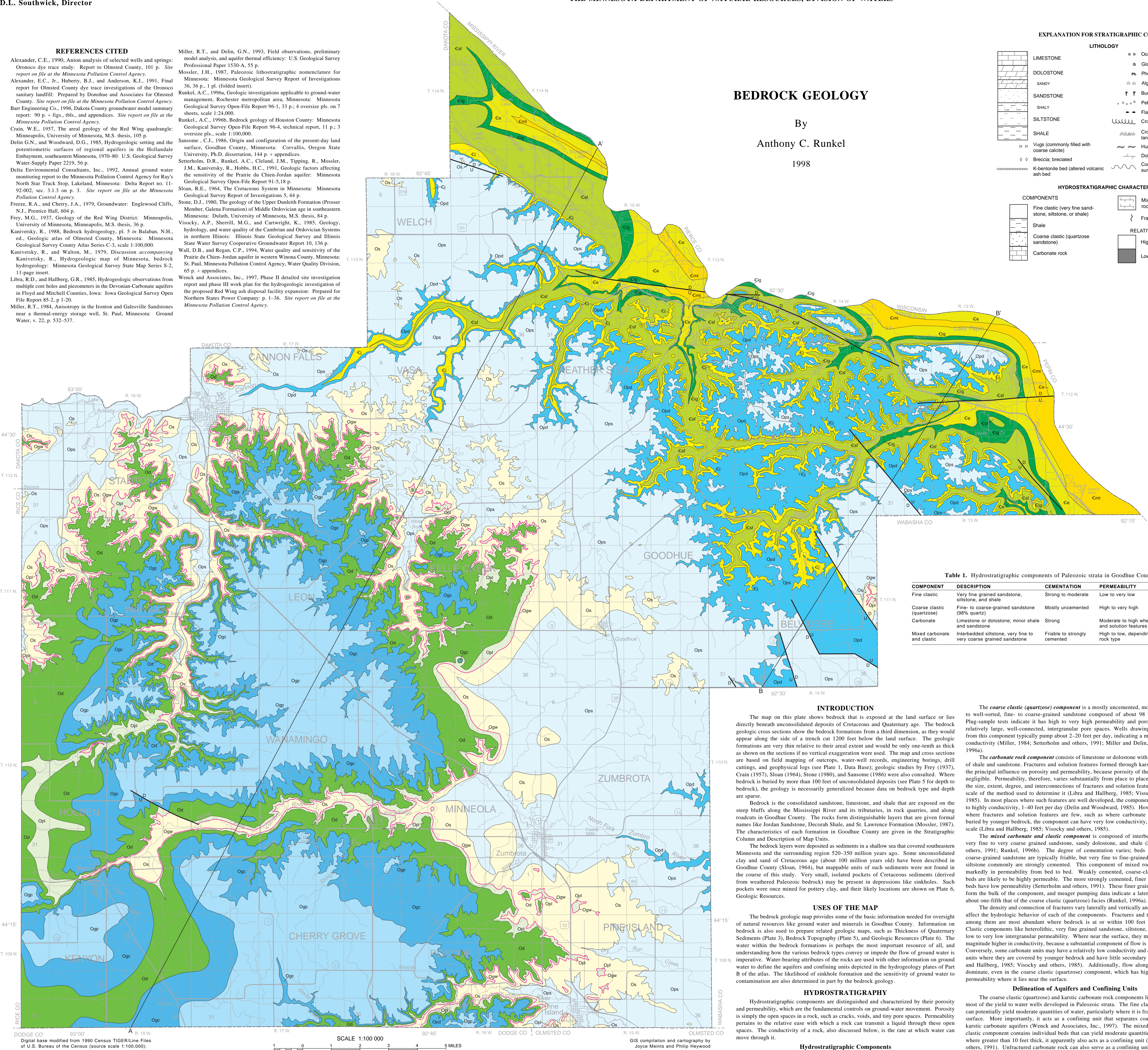


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BEDROCK GEOLOGY

By
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1998

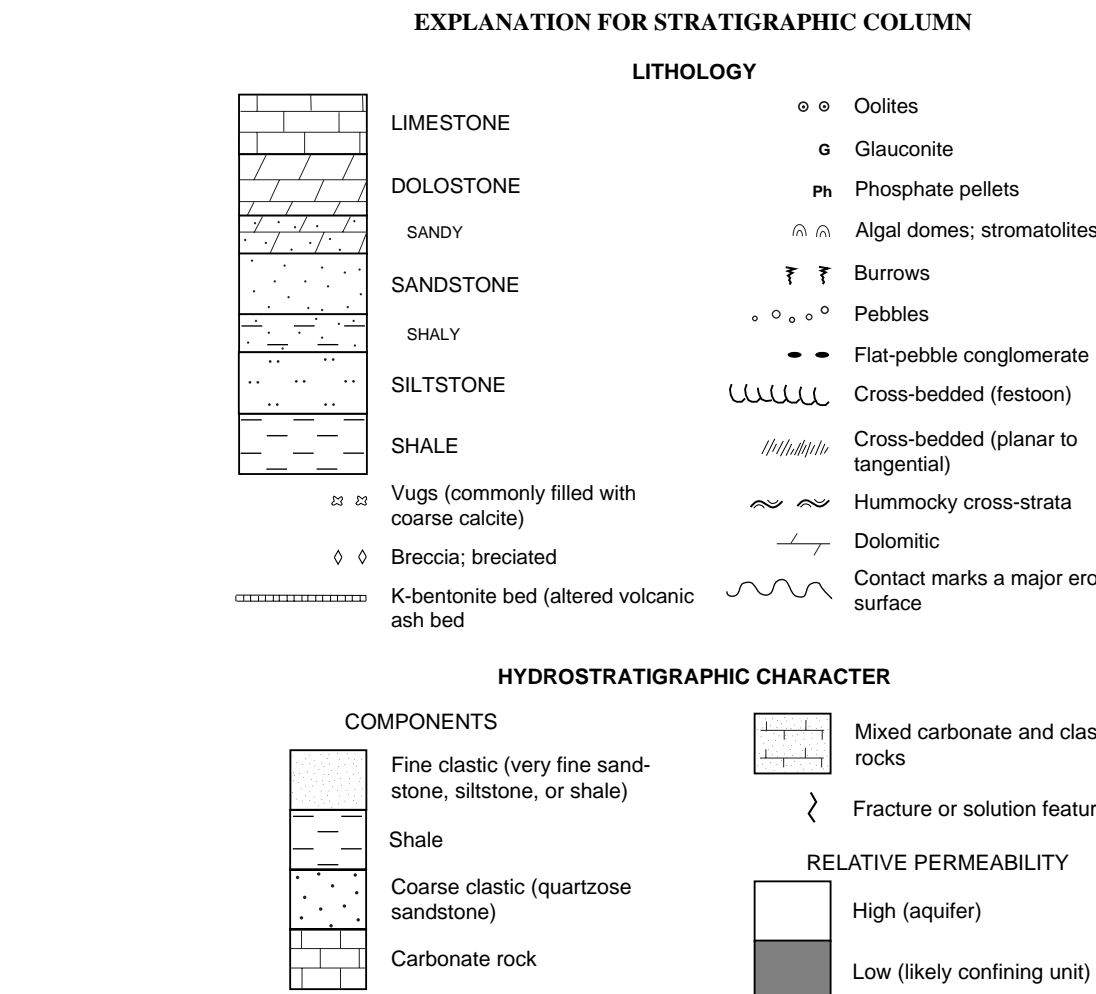


Table 1. Hydrostratigraphic components of Paleozoic strata in Goodhue County.

COMPONENT	DESCRIPTION	CEMENTATION	PERMEABILITY
Fine clastic	Very fine grained sandstone, siltstone, and shale	Strong to moderate	Low to very low
Coarse clastic (quartzite)	Fine- to coarse-grained sandstone (98% quartz)	Mostly uncemented	High to very high
Carbonate	Limestone or dolostone, minor shale and sandstone	Strong	Moderate to high where fractures and solution features are present
Mixed carbonate and clastic	Interbedded siltstone, very fine to very coarse grained sandstone	Friable to strongly cemented	High to low, depending on dominant rock type

INTRODUCTION

The map on this plate shows bedrock that is exposed at the land surface or lies directly beneath unconsolidated deposits of Cretaceous and Quaternary age. The bedrock geologic cross sections show the bedrock formations from a third dimension, as they would appear along the side of a trench cut 1200 feet below the land surface. The geologic formations are very thin relative to their areal extent and would be only one-tenth as thick as shown on the sections if no vertical exaggeration were used. The map and cross sections are based on field mapping of outcrops, water-well records, engineering borings, drill cuttings, and geophysical logs (see Plate 1, Data Base); geologic studies by Frey (1937), Crain (1957), Sloan (1964), Stone (1980), and Sansone (1986) were also consulted. Where bedrock is buried by more than 100 feet of unconsolidated deposits (see Plate 5 for depth to bedrock), the geology is necessarily generalized because data on bedrock type and depth are sparse.

Bedrock is the consolidated sandstone, limestone, and shale that are exposed on the steep bluffs along the Mississippi River and its tributaries, in quarries, and along roadcuts in Goodhue County. The rocks from distinguishable layers that are given formal names like Jordan Sandstone, Decorah Shale, and St. Lawrence Formation (Mossler, 1987). The characteristics of each formation in Goodhue County are given in the Stratigraphic Column and Description of Map Units.

The bedrock layers were deposited as sediments in a shallow sea that covered southeastern Minnesota and the surrounding region 520-350 million years ago. Some unconsolidated clay and sand of Cretaceous age (about 100 million years old) have been deposited in Goodhue County (Sloan, 1964), but mappable units of such sediments were not found in the course of this study. Very small, isolated pockets of Cretaceous sediments (derived from weathered Paleozoic bedrock) may be present in depressions like sinkholes. Such pockets were once mined for pottery clay, and their likely locations are shown on Plate 6, Geologic Resources.

USES OF THE MAP

The bedrock geologic map provides some of the basic information needed for oversight of natural resources like ground water and minerals in Goodhue County. Information on bedrock is also used to prepare related geologic maps, such as Thickness of Quaternary Sediments (Plate 3), Bedrock Topography (Plate 5), and Geologic Resources (Plate 6). The water within the bedrock formations is perhaps the most important resource of all, and understanding how the various bedrock types convey or impede the flow of ground water is imperative. Water-bearing attributes of the rocks are used with other information on ground water to define the aquifers and confining units depicted in the hydrogeology plates of Part B of the atlas. The likelihood of sinkhole formation and the sensitivity of ground water to contamination are also determined in part by the bedrock geology.

HYDROSTRATIGRAPHY

Hydrostratigraphic components are distinguished and characterized by their porosity and permeability, which are the fundamental controls on ground-water movement. Porosity is simply the open spaces in a rock, such as cracks, voids, and tiny pore spaces. Permeability pertains to the relative ease with which a rock can transmit a liquid through those open spaces. The conductivity of a rock, also discussed below, is the rate at which water can move through it.

Hydrostratigraphic Components

The Paleozoic bedrock in Goodhue County consists of four distinct hydrostratigraphic components, which have been defined and characterized in studies elsewhere in southeastern Minnesota (Setterholm and others, 1991; Miller and Delin, 1993; Runkel, 1996b). The components are (1) fine clastic, (2) coarse clastic or quartzite, (3) mixed carbonate and clastic, and (4) carbonate. A clastic rock is a sedimentary rock composed principally of broken fragments derived from pre-existing rocks. The stratigraphic position of these components relative to the formally defined groups, formations, and members of the Paleozoic rocks is shown in the Stratigraphic Column. Porosity and permeability were determined through laboratory tests of plug samples and hydraulic testing of water wells in southeastern Minnesota, including Goodhue County.

The **fine clastic component** consists of very fine grained sandstone, siltstone, and shale in thin to medium-thick beds that are strongly to moderately cemented. The component has low to very low relative permeability, several orders of magnitude less than that of the coarser grained sandstone of the coarse clastic (quartzite) component. Vertical conductivity is low to very low in the fine clastic component, commonly 0.001-0.0001 (10^{-3} - 10^{-5}) feet per day for interbedded, very fine sandstone and shale (Miller and Delin, 1993), and as low as 0.0000001 (10^{-7}) feet per day for units composed almost entirely of shale (Freese and Cherry, 1979). Horizontal conductivity in interbedded sandstone and shale is typically more than 100 times greater than vertical permeability (Miller, 1984; Setterholm and others, 1991; Miller and Delin, 1993).

The **coarse clastic (quartzite) component** is a mostly uncemented, moderately sorted to well-sorted, fine- to coarse-grained sandstone composed of about 98 percent quartz. Plug-sample tests indicate it has high to very high permeability and porosity due to its relatively large, well-connected, intergranular pore spaces. Wells drawing water mostly from this component typically pump about 2-20 feet per day, indicating a moderate to high conductivity (Miller, 1984; Setterholm and others, 1991; Miller and Delin, 1993; Runkel, 1996a).

The **carbonate rock component** consists of limestone or dolostone with minor amounts of shale and sandstone. Fractures and solution features formed through karst processes are the principal influence on porosity and permeability, because porosity of the rock matrix is negligible. Permeability, therefore, varies substantially from place to place, depending on the size, extent, degree, and interconnections of fractures and solution features, and on the scale of the method used to determine it (Libra and Hallberg, 1985; Visocky and others, 1985). In most places where such features are well developed, the component has moderate to highly conductivity, 1-40 feet per day (Delin and Woodward, 1985). However, in places where fractures and solution features are few, such as where carbonate rock is deeply buried by younger bedrock, the component can have very low conductivity, even at a large scale (Libra and Hallberg, 1985; Visocky and others, 1985).

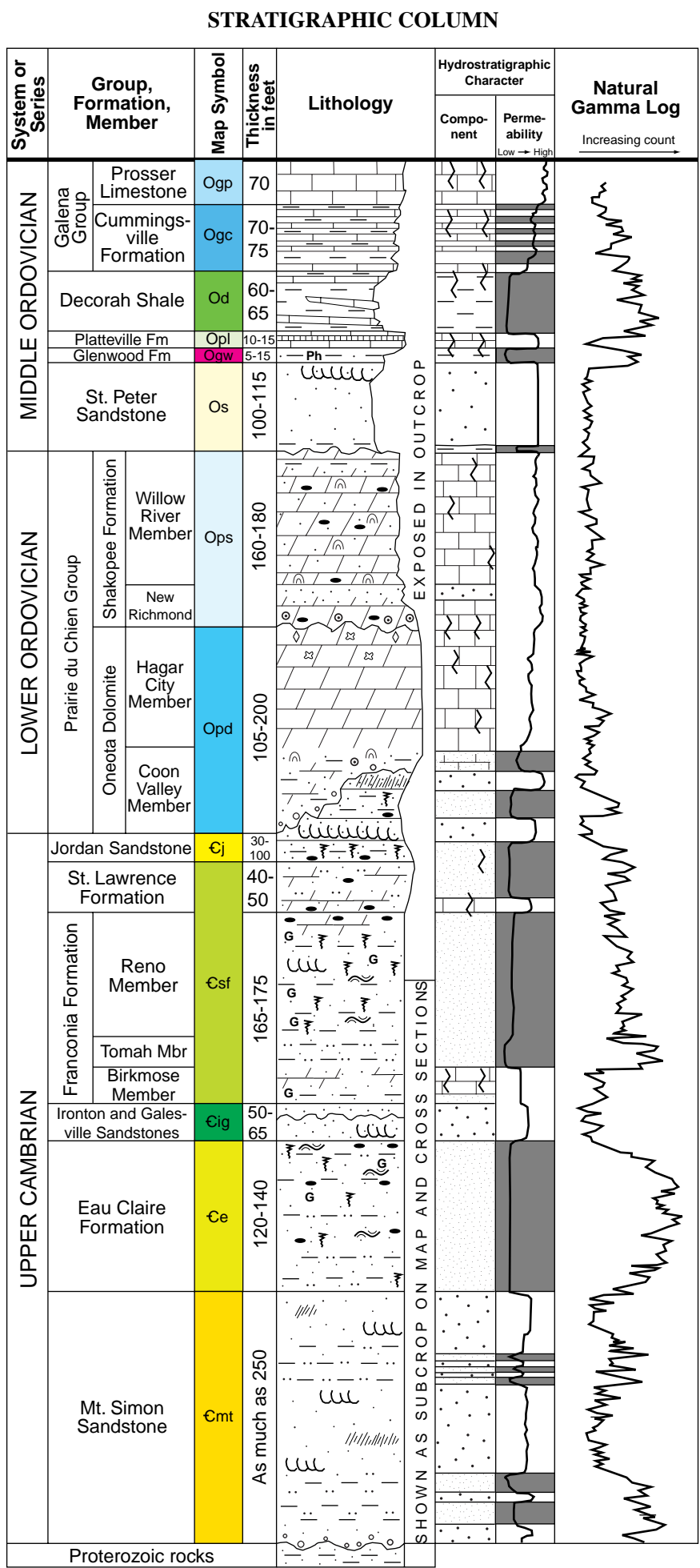
The **mixed carbonate and clastic component** is composed of interbedded siltstone, very fine to very coarse grained sandstone, sandy dolostone, and shale (Setterholm and others, 1991; Runkel, 1996b). The degree of cementation varies; beds of medium- to coarse-grained sandstone are typically friable, but very fine to fine-grained sandstone and siltstone commonly are strongly cemented. This component of mixed rock types varies markedly in permeability from bed to bed. Weakly cemented, coarse-clastic sandstone beds are likely to be highly permeable. The more strongly cemented, fine grained, clastic beds have low permeability (Setterholm and others, 1991). These finer grained clastic beds from the bulk of the component, and meager pumping data indicate a lateral conductivity about one-fifth that of the coarse clastic (quartzite) facies (Runkel, 1996a).

The density and connection of fractures vary laterally and vertically and can markedly affect the hydrologic behavior of each of the components. Fractures and the connections among them are most abundant where bedrock is at or within 100 feet of the surface. Clastic components like heterolithic, very fine grained sandstone, siltstone, and shale have low to very low intergranular permeability. Where near the surface, they may be orders of magnitude higher in conductivity, because a substantial component of flow is along fractures. Conversely, some carbonate units may have a relatively low conductivity and act as confining units where they are covered by younger bedrock and have little secondary porosity (Libra and Hallberg, 1985; Visocky and others, 1985). Additionally, flow along fractures may dominate, even in the coarse clastic (quartzite) component, which has high intergranular permeability where it lies near the surface.

Delineation of Aquifers and Confining Units

The coarse clastic (quartzite) and karstic carbonate rock components likely contribute most of the yield to water wells developed in Paleozoic strata. The fine clastic component can potentially yield moderate quantities of water, particularly where it is fractured near the surface. More importantly, it acts as a confining unit that separates coarse clastic and karstic carbonate aquifers (Wenck and Associates, Inc., 1997). The mixed carbonate and clastic component contains individual beds that can yield moderate quantities of water, but where greater than 10 feet thick, it apparently also acts as a confining unit (Setterholm and others, 1991). Unfractured carbonate rock can also serve as a confining unit (Visocky and others, 1985; Alexander and others, 1991; Barr Engineering, 1996).

Two of the most widely used aquifers in Goodhue County, the Franconia-Ironton-Galeville and the Prairie du Chien-Jordan and are not single, hydraulically connected aquifer systems as previously believed (Kanivetsky and Walton, 1979). Pumping tests (Miller, 1984; Delta Environmental Consultants, Inc., 1992; Miller and Delin, 1993) and carefully collected measurements of local static water levels (Delta Environmental Consultants, Inc., 1992; Wenck and Associates, Inc., 1997) clearly indicate that water in the upper part of the Franconia is hydraulically separated from water in the lowermost Franconia, Ironton, and Galeville formations. Some fractured, carbonate-cemented rock in the lower part of the Franconia where it is at or near the surface is a source of many springs in the county and is perhaps the only highly permeable conduit for ground water within the Franconia. The Prairie du Chien-Jordan aquifer is also two distinct aquifers, an upper carbonate aquifer and a lower, fine-grained, quartzite aquifer, which are separated by an intervening confining unit composed of the mixed clastic and carbonate component. Hydraulic separation of the carbonate and quartzite aquifers is indicated by several lines of hydrologic evidence gathered in Goodhue and adjacent counties, including potentiometric data (Kanivetsky, 1988; Alexander and others, 1991), pumping tests (Barr Engineering, 1996), and ground-water chemistry (Alexander, 1990; Setterholm and others, 1991; Wall and Regan, 1994).



DESCRIPTION OF MAP UNITS

- Ogp** **Prosser Limestone**—Very fine grained, thin- and crinkly bedded limestone; dolomitic near top. Fossils form thin coquina layers. Distinguished from Cummingsville Formation below by near-absence of shale interbeds. As much as 70 feet thick.
- Ogc** **Cummingsville Formation**—Interbedded limestone and shale. Shale is green-gray, calcareous, thick bedded in lower part. Limestone is fine grained, fossiliferous, thin and crinkly bedded. Unit presents a sawtooth profile in exposure owing to the interbedding of weathered, soft, recessive shale and hard limestone. Unit thickness, 70-75 feet.
- Ogd** **Decorah Shale**—Green-gray shale with thin interbeds of fossiliferous limestone. Ferruginous nodules at top. Unit thickness, 60-65 feet.
- Opl** **Plattville Formation**—Fine-grained, fossiliferous, thin- to medium-bedded limestone; sandy at base. Thin shale beds are most common in upper part. Contacts with units above and below are gradational. Unit forms prominent ledge where it caps small plateaus. Unit thickness, 10-15 feet.
- Ogw** **Glenwood Formation**—Sandy, green-gray shale containing phosphatic grains as much as one centimeter in diameter. Thin, quartzose, fine- to coarse-grained sandstone interbeds are common. Unit thickness, 5-15 feet.
- Oss** **St. Peter Sandstone**—Mostly very fine grained to medium-grained, poorly cemented sandstone. Lacks structure or, less commonly, shows subtle cross-stratification, especially in uppermost part. Some intensely burrowed, pale-green shale intervals. Grain size becomes progressively finer upward in lower half, coarser upward in upper half. A shale bed as thick as one foot in lower three feet of formation extends laterally at least across the northern part of county. Possible unconformity along basal contact. Commonly exposed along steep hill slopes that are held in place by caps of Plattville Formation. Unit thickness, 100-115 feet.
- Ops** **Shakopee Formation**—160-180 feet thick.
- Opr** **Willow River Member**—Thin to medium-bedded dolostone, sandstone, sandy dolostone, and minor amount of shale. As much as 150 feet thick.
- Opr** **New Richmond Member**—Quartzose sandstone as much as eight feet thick overlying intraclastic, oolitic dolostone and sandy dolostone. Basal contact is a disconformity. As much as 50 feet thick.
- Opr** **Owata Dolomite**—105-200 feet thick.
- Opr** **Hager City Member**—Dolostone and silty dolostone as much as 115 feet thick in medium to thick, irregular, tabular beds. Most beds are internally structureless or faintly laminated, and have relatively minor vuggy porosity. Some beds have algal lamination and are stromatolitic and vuggy, with secondary porosity and calcite mineralization.
- Opr** **Coon Valley Member**—Interbedded sandstone, sandy dolostone, and minor amount of shale; member thickness, 20-85 feet. Lower contact is an unconformity, which is directly overlain by a poorly sorted sandstone bed containing pebbles of Precambrian rocks that are as much as two centimeters in diameter.
- Opr** **Jordan Sandstone**—Sandstone consisting of a coarsening-upward sequence of two distinct facies: (1) quartzose facies of mostly friable, yellow to white sandstone, and (2) feldspathic facies of very fine grained sandstone, siltstone, and shale. About 30-100 feet thick.
- Opr** **St. Lawrence Formation and Franconia Formation**.
- Opr** **St. Lawrence Formation**—Tan to gray, well-cemented, thin- to medium-bedded siltstone and siltstone; thin shale beds. Dolostone contains variable amounts of clay, silt, sand, and glauconitic. Thin to medium beds of very fine grained sandstone are common, particularly in upper 20 feet. Unit thickness, 40-50 feet.
- Opr** **Franconia Formation**—Mostly glauconitic, feldspathic, very fine to fine-grained sandstone; green and gray shale and pink or tan, sandy, glauconitic dolostone. Intracasts and burrow mottling are common. Generally coarser grained and more poorly cemented than St. Lawrence. About 160-175 feet thick.
- Opr** **Reno Member** (upper 90-100 feet)—Very fine grained to fine-grained glauconitic sandstone interbedded with siltstone and shale.
- Opr** **Tomah Member** (medial 40 feet)—Interbedded, very fine grained sandstone, siltstone, and shale; minor amount of glauconitic. This member is fine grained and has more shale than adjacent members.
- Opr** **Birkmore Member** (basal 30 feet)—Very fine grained to fine-grained sandstone; abundant glauconitic. Dolomite cement and sandy dolostone beds are common.
- Opr** **Ironton Sandstone and Galeville Sandstone**—Fine-grained to very coarse grained quartzose sandstone. Total unit thickness, 50-65 feet.
- Opr** **Ironton Sandstone**—Ironton is more poorly sorted than Galeville and has coarser sandstone beds. Substantial shale and siltstone form thin interbeds or a matrix in poorly sorted sandstone. White, brown, or black shell fragments are locally common in upper 10-15 feet. Subtle disconformity in middle of Ironton is capped by pebbly, coarse to very coarse sandstone bed. Above this bed, grain size of Ironton becomes finer upward and passes transitionally into the Franconia Formation; below this bed, grain size becomes finer downward.
- Opr** **Galeville Sandstone**—Fine to coarse grained, well to moderately sorted; minor amounts of shale, siltstone, and very fine grained sandstone. Lower one-third locally intertongues with feldspathic, very fine grained sandstone of underlying Eau Claire Formation.
- Opr** **Eau Claire Formation**—Commonly interbedded sandstone, siltstone, shale; thin to medium-thick beds. The sandstone is very fine grained to fine grained, tan, variably glauconitic, laterally stratified, hummocky stratified or bioturbated. Siltstone is tan to gray, laterally stratified or bioturbated. Shale is gray to greenish-gray. Gray to black shell fragments are common. Unit coarsens upward, with shale and siltstone replaced in abundance aspection by sandstone. Uppermost 10-20 feet is mostly very fine grained sandstone and siltstone. About 120-140 feet thick.
- Opr** **Mt. Simon Sandstone**—Mostly light to yellow, fine- to coarse-grained, friable, quartzose sandstone. Scant subsurface data indicate that the Mt. Simon is as much as 250 feet thick. The top of the Mt. Simon is marked locally by a thin "rusty" sandstone that contains iron-coated, fine to coarse sand grains and abundant black shell fragments. Beds of variegated shale, siltstone, and feldspathic, very fine grained sandstone are common, particularly in the upper two-thirds of the formation. Pebble conglomerate or pebbly sandstone is common in the lowermost 100 feet of the formation.
- Proterozoic rocks, undifferentiated**—Samples from a few deep water wells that penetrated the entire Mt. Simon beneath the city of Red Wing indicate that the rocks beneath the Mt. Simon include buff to tan quartz arenite of the Hinckley Sandstone and arkosic red sandstone, shale, and siltstone of the Fond du Lac Formation.

DESCRIPTION OF MAP SYMBOLS

- Geologic contact**—Approximately located; generally concealed.
- U** **Fault**—Approximately located; generally concealed. U, upthrown side; D, downthrown side.
- A—A'** **Line of section.**

Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based, however, the Minnesota Geological Survey does not warrant or guarantee any results. Users may wish to verify critical information; sources include both the references listed here and information on file at the offices of the Minnesota Geological Survey in St. Paul. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown is rigorously correct, however, it is intended not to be used to guide engineering-scale decisions without site-specific verification.